APL - North Pacific Acoustic Laboratory

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http://www.apl.washington.edu/projects/blue_water/index.html

LONG-TERM GOALS

The ultimate limitations to the performance of long-range sonar are due to ocean sound speed perturbations and the characteristics of the ambient acoustic noise field. Scattering and diffraction resulting from internal waves and other ocean processes limit the temporal and spatial coherence of the received signal, while the ambient noise field is in direct competition with the received signal. Research conducted in the North Pacific Acoustic Laboratory (NPAL) program at the Applied Physics Laboratory (APL-UW) is directed toward a complete understanding of the basic physics of low-frequency, long-range, deep water, broadband acoustic propagation, the effects of ocean variability on signal coherence, and the fundamental limits to signal processing at long-range that are imposed by ocean processes. The long-term goal of NPAL is to optimize advanced signal processing techniques, including matched-field processing and adaptive array processing methods, based upon knowledge about the multi-dimensional character of the propagation and noise fields and their impact on long-range ocean acoustic signal transmissions.

OBJECTIVES

The scientific objectives of the North Pacific Acoustic Laboratory are:

1. To study the spatial and temporal coherence of long-range, low-frequency resolved rays and modes and the dependence upon ocean processes, transmission distance, and signal frequency.
2. To explore the range and frequency dependence of the higher order statistics of resolved ray and mode arrivals and of the highly scattered finale observed in previous experiments.
3. To define the characteristics and trends, and determine the relative causes of low-frequency ambient noise on ocean basin scales.

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **30 SEP 2013**	2. REPORT TYPE	3. DATES COVERED **00-00-2013 to 00-00-2013**
4. TITLE AND SUBTITLE **APL - North Pacific Acoustic Laboratory**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,Applied Physics Laboratory,1013 NE 40th St,Seattle,WA,98105**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**15**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

4. To elucidate the roles of internal waves, ocean spice, internal tides, fronts and eddies in causing fluctuations in acoustic receptions.
5. To improve basin-scale ocean sound-speed predictions via assimilation of acoustic travel-time and other data into numerical ocean-dynamic models.
6. To fully analyze our experiment in the Philippine Sea, the results of which will support all of the objectives listed above.

APPROACH

APL-UW employs a combination of experimental measurements, data analysis, simulations, and theoretical development to address the objectives outlined above. These activities are funneled through two primary avenues. ***The North Pacific Ambient Noise Laboratory***, operated and maintained by APL-UW, provides a full-time laboratory for real-time acoustic measurements at a selection of basin-scale locations, the capability to test various transmission signals, and ambient noise (including marine mammals) measurements in the NE Pacific Ocean. The Laboratory consists of legacy SOSUS hydrophone receivers in the Pacific Ocean, and a data processing and archive center at the Applied Physics Laboratory.

The second avenue includes highly focused, comparatively short-term experiments.
We have completed a pilot study/engineering test and an experiment in the ***Philippine Sea*** called **PhilSea9** and **PhilSea10**, respectively [1]. See Figure 1. The principal elements of the APL-UW effort during the 2010 experiment were: 1) a 55-hour continuous transmission from ship stop SS500 at 500 km from the DVLA and a depth of 1000 m, 2) a tow of a CTD Chain along the path toward the Distributed Vertical Line Array (DVLA) from SS500, 3) a source tow at a depth of 150 m at ranges between 25 and 43 km from the DVLA through the region of a Reliable Acoustic Path (RAP) from the near-surface region to the water column bottom, 4) a series of CTD casts every 10 km from the DVLA back to SS500, and 5) a 55-hour continuous transmission from SS500 at a depth of 1000 m to the DVLA. The primary institutions participating in PhilSea10 were APL-UW, the Scripps Institution of Oceanography (SIO), and the Massachusetts Institute of Technology (MIT).

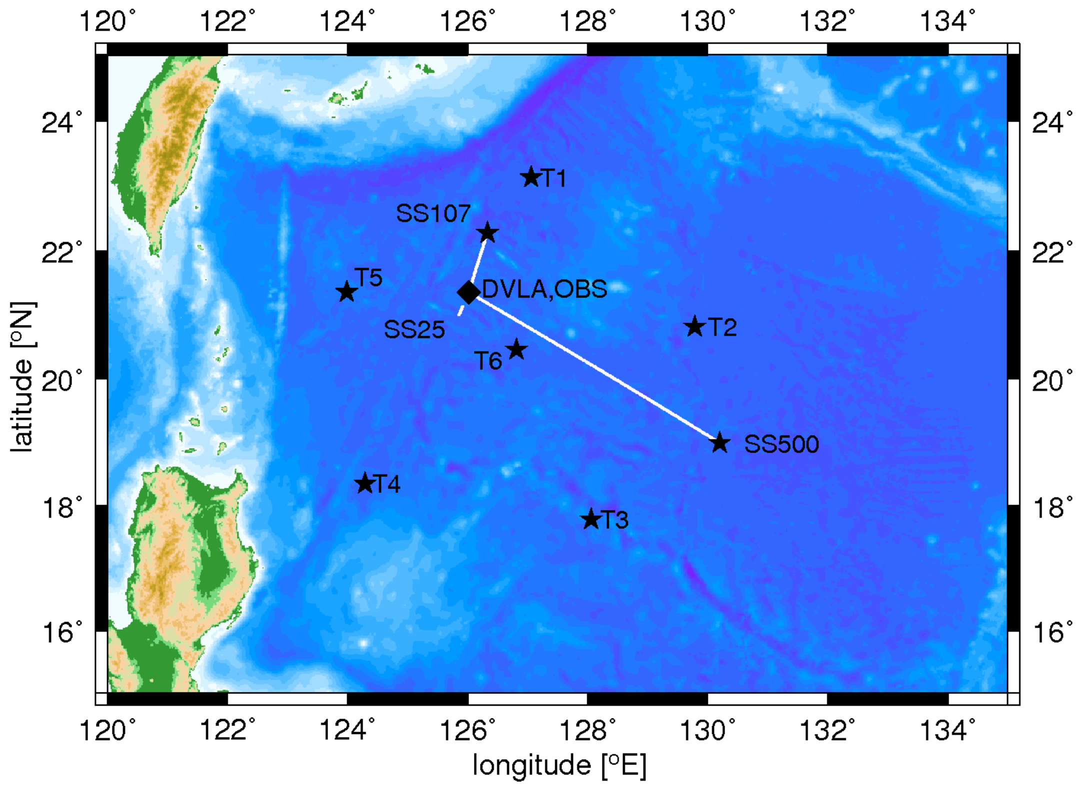

Figure 1. Principal activity locations for PhilSea9 and PhilSea10

WORK COMPLETED

Preliminary processing on the **PhilSea10** data was completed in order to verify that we had good data in preparation for more refined processing. This involved modifying the existing processing code for the actual transmissions from both the HX554 and MP200 acoustic sources. The data were then batch processed through the clock correction, filtering, resampling, and pulse compression steps in the modified code.

The major task during the past year has been the detailed analysis of processed data from **PhilSea9** and **PhilSea10**. Although much work remains, eight (8) publications were authored and/or co-authored and accepted for publication in the Journal of the Acoustical Society of America, and others are in preparation. (See the Publications Section for details.)

Andrew White completed the requirements for the PhD degree in Geophysics at the University of Washington. These requirements included a thesis defense presentation at the APL/UW in August, 2013, and submission of his PhD thesis, titled “Underwater Acoustic Propagation in the Philippine Sea: Intensity Fluctuations”.

As part of our participation and support to the greater NPAL community we provided data and data processing assistance to several investigators. For example:

(1) We provided **PhilSea10** CTD and ADCP data to Dr. Steven Ramp at Soliton.

(2) We provided **LOAPEX** CNAV data to Dr. Percival at APL.

(3) We provided the following **PhilSea10** items to Dr. Gerald D'Spain at Scripps.

(a) Developed code to calculate range and depth versus time from the echo sounder data; and provided the results.

(b) Sent the DVLA raw and processed hydrophone data.

(c) Sent the full ocean depth CTD data nearest the test drift in location and time.

(d) Sent the parameters for the HX554 source during the drift test.

The NPAL North Pacific Ambient Noise Laboratory was installed in the early 1990s as part of the Acoustic Thermometry of Ocean Climate program and utilizes undersea hydrophone arrays owned by the US Navy. In addition, shore-based receiver equipment is located at a Navy shore facility. Complicating the transfer of data media and hardware components from the shore site to APL-UW are the required auditable trails of information on storage media and hardware. The current procedures, protocols, and documentation requirements devised and negotiated by APL-UW and Navy personnel for these transfers are described in Ref [2]. Due to the aging receiver equipment several equipment failures have occurred over the past year. We have copied the data from this period onto external drives and brought it back to APL. An extensive effort was made to identify and remove all the bad data files automatically generated during the failures. The remaining good files were then burned onto DVDs and stored in a classified room at APL-UW. All security paperwork was updated accordingly.

Following the Base Realignment and Closure action for NAS Barbers Point, the SOSUS cable termination building remained available as a shore site for several years until last year. All APL-UW equipment for this site was subsequently re-calibrated, removed and placed in storage in Hawaii. Application to a land-board was submitted to re-locate the receiver equipment over the cable route on Navy controlled property but no decision was forth coming. After a year in storage the equipment was given to the University of Hawaii.

NEW RESULTS

There has been significant progress on the analysis of data from **PhilSea9**. At the time of last year's report, acoustic intensity arriving at the upper sub-array of the DVLA along three paths had been processed for three of its 30 hydrophones. Now receptions of these paths and one additional path at all 30 hydrophones have been processed.

At most of the hydrophones of the upper sub-array, it was possible to separate in time the energy arriving along four distinct paths from the transmitter to the DVLA. One path left the transmitter at a downward angle and had three turns before reaching the DVLA; this path was therefore designated 'ID-3': the '-' indicates a downward angle from the source and the '3' indicates the three turns. The other paths were ID+4, ID-4, and ID+5.

At some depths, particular paths could not be separated from other paths. Acoustic intensity time series for paths with ID-3 and ID+4 at all hydrophones for which the paths were separable from other paths are shown in Figures 2 and 3. The plots for paths ID-4 and ID+5 are similar to the plot for ID+4, and are omitted here for brevity. Intensity fades of about 10 dB and with durations of approximately

18 and 12 hours, respectively, are visible at hydrophone depths greater than about 1150 m in path ID-3 during year days 118 and 119, shown in Figure 2. Similar fades are not observed in the time series for the other paths.

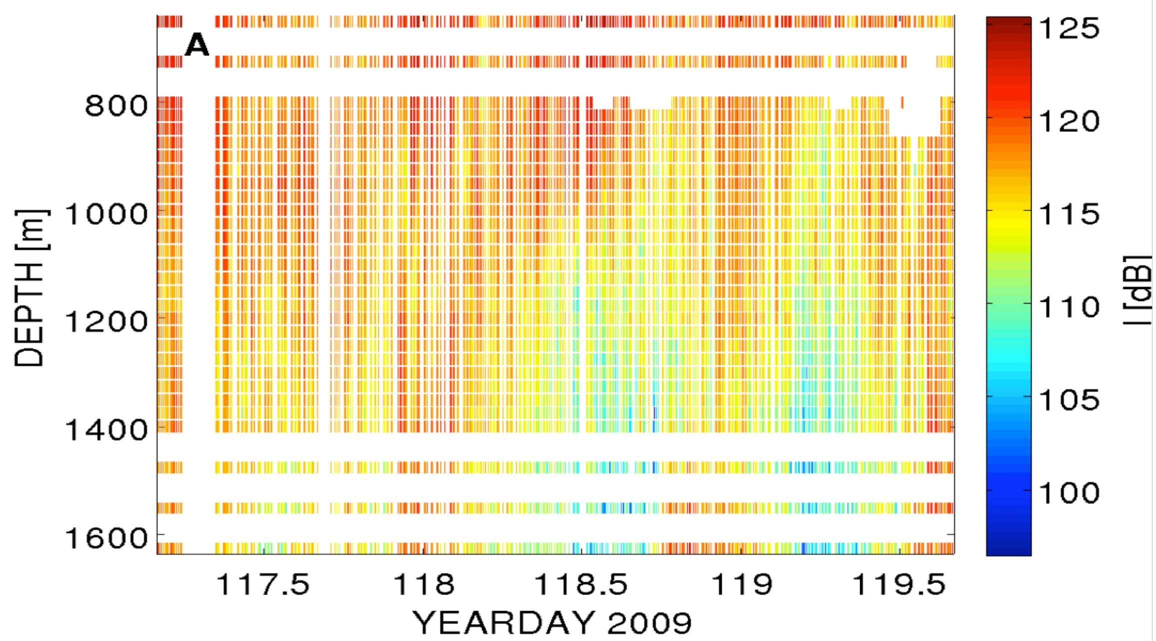

Figure 2. Measured intensities of all good receptions on the upper array of the DVLA for path ID-3. Intensity is represented by color in 22 m-wide bands in depth, centered on the depth of the corresponding hydrophone for clarity of presentation. At some of the shallowest hydrophones on the array, some further data were excluded—apparent here, and in figure 3 as white patches.

As was described in the annual report for FY2012, two Monte Carlo parabolic equation (MCPE) simulations were carried out (these were of multi-month duration and were still running at the writing of the FY2012 report). The purpose of these simulations was to determine if fluctuations in the intensity of the received signal, imparted by the oceanography of the Philippine Sea—which is characterized by energetic mesoscale and strong local internal tides—would be correctly predicted by a model composed only of a diffuse background of internal waves. In these simulations, the environment therefore consisted of a smooth, average background sound-speed profile plus random perturbations due to internal waves, as described by the Garrett-Munk '79 [3] model.

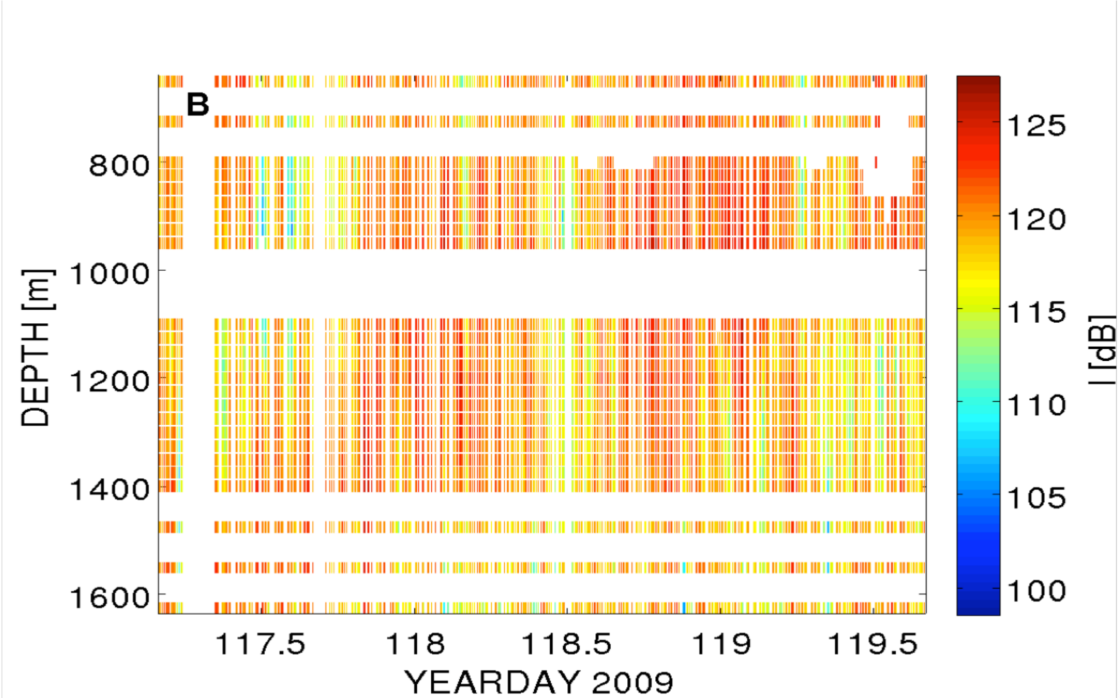

Figure 3. Measured intensities of all good receptions on the upper array of the DVLA for path ID+4.

In the first simulation, termed the 'time-independent' Monte Carlo Parabolic Equation (TI MCPE), 226 independent random oceans were constructed. In the second, termed the 'time-dependent' (TD MCPE) simulation, a single random ocean was evolved in time at a 240-s time-step for 320 hours (a total of 4800 time-steps). Broadband propagation through each ocean (or at each time-step) was computed and acoustic arrivals were separated in time in the same way as was done with the measured data. The only adjustment made to the Garrett-Munk '79 model was to set the variance of the internal wave displacements according to an estimate made from measurements taken by CTD instruments on the DVLA. An example set of time series from the TD MCPE simulation is shown in Figure 4. Time series for the other arrivals are similar, and are omitted for brevity.

The variance of the intensity normalized by the mean intensity squared is the scintillation index (SI), a fourth moment of the acoustic field. This moment was computed from the measured data and from the TI MCPE simulation for each path ID at all depths where paths were separable; the model-data comparison is shown in Figure 5. The rms log-amplitude, σ_ι, is also shown in the same Figure. The MCPE and data 95% confidence intervals on the SI and σ_ι overlap for ID+4, ID-4, and ID+5 at all hydrophone depths. The confidence intervals for data and simulation overlap for ID-3 for depths shallower than 1150 m, though the prediction is consistently slightly smaller than the measured value. The confidence intervals do not overlap for ID-3 for hydrophone depths deeper than 1150 m.

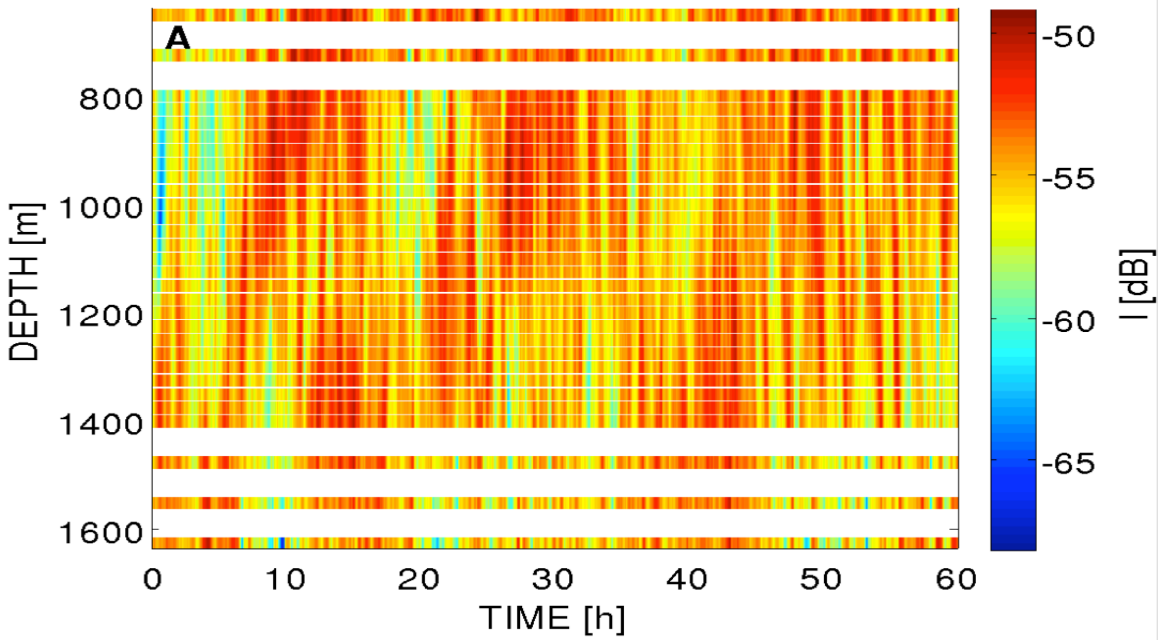

Figure 4. Shown here are 60 h out of the 320 h of simulated intensities of arrival ID-3. Time-series are computed at a vertical spacing of 1 m depth in the simulation, but only data at the hydrophone depths are shown here. Data have been spread over adjacent depths in the same manner as in the plots of the measured data in Figures 2 and 3.

Histograms of intensity normalized by the mean intensity computed from data and from the TD MCPE simulation are compared in Figure 6. Intensities at each depth were sorted into bins with a width of 0.05, and with bin edges ranging from 0 to 3.5. The resulting histogram counts were normalized by the total number of intensities that were recorded at that depth. For reference, 5% and 1% represent counts of 785 and 157, respectively, for the measured data, and 240 and 48, respectively, for the simulated data. The distributions of measured intensities exhibit depth-dependence and structure that appear to be consistent across multiple hydrophones. The distribution at several depths around 1300 m appears to be bi-modal for ID+4; the same is true at 725 m for ID-4, and at various depths for ID+5. The mode of the distributions of ID-3 are shifted increasingly with depth toward low intensities for hydrophones below about 1150 m, and the distribution widens with depth, with more high intensities on the deeper hydrophones. The low-intensity mode of the ID-3 distribution is consistent with the intensity fading seen in Figure 2.

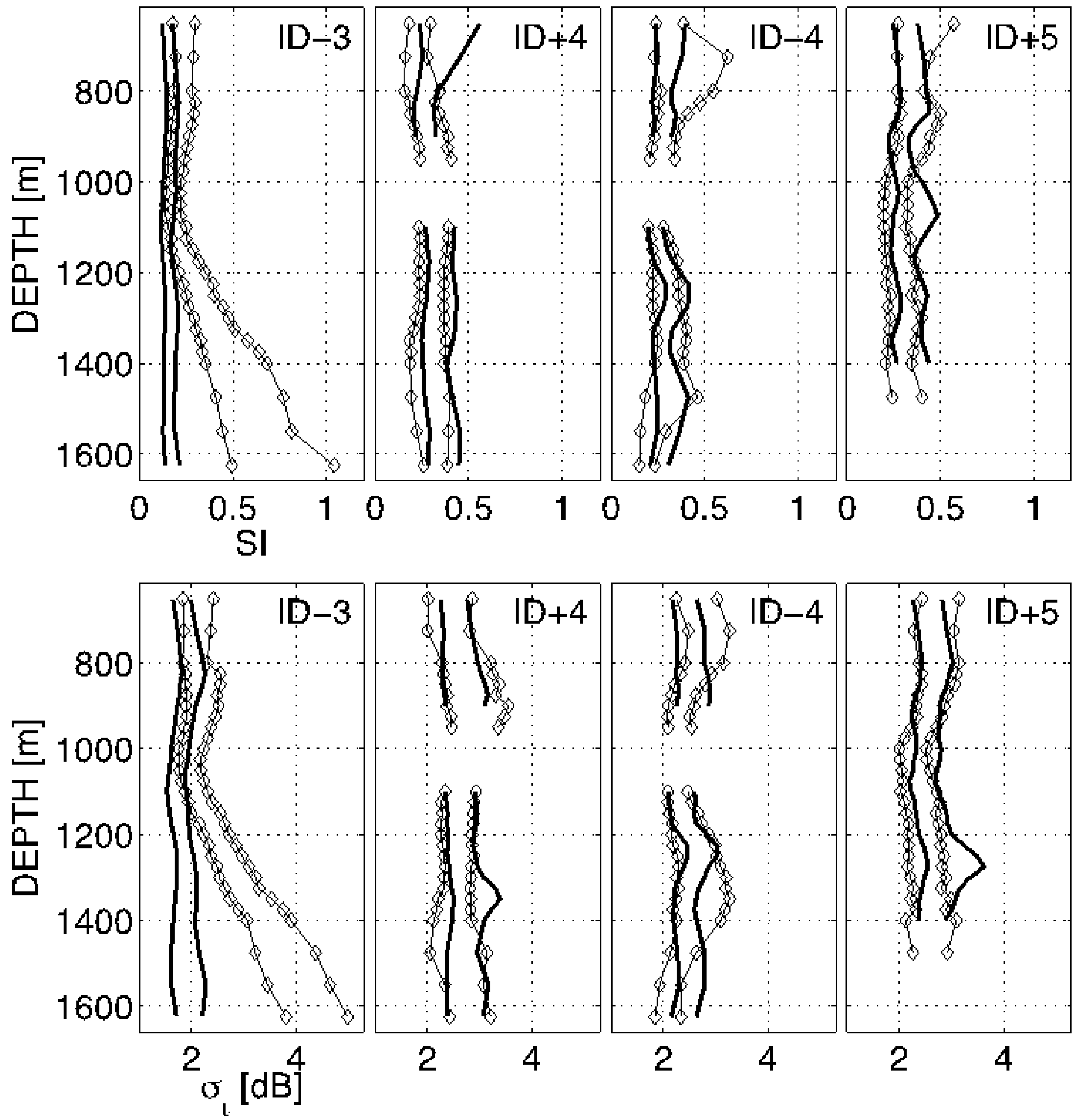

Figure 5. Top row: comparison of TI MCPE predictions of SI with measured values. The curves give the 2.5% and 97.5% percentiles—hence the 95% confidence intervals. Bold curves show the MCPE confidence intervals and curves with diamonds show confidence intervals on the measured values. Diamonds indicate the depths at which the measurements were made. The bottom row shows the same for σ_ι.

The distributions of the TD MCPE intensities are seen to be uni-modal for all four paths and at all depths for which paths could be separated. The MCPE distribution for ID-3 is noticeably narrower than for the other paths, apparent in the width of the light-blue portion of the histograms—as well as having a mode at a slightly higher intensity. The MCPE histograms appear otherwise to be quite similar to each other over the full range of receiver depths.

Despite the simplification of range-independence and the exclusion of internal tides from MCPE model simulations, the predictions of the SI, σ_ι, and the distribution of $I/\langle I\rangle$ for paths with UTPs below the extreme upper ocean generally agree with observations—the only model adjustment made was of the

GM strength. This conclusion is in agreement with the results presented in Colosi et al. (2013) [4] (to the extent that the MCPE model provides a validation of the ocean model), who studied the PhilSea09 environmental measurements more extensively. Their results were consistent with the GM spectral model's assumptions of horizontal isotropy and homogeneity (for diffuse internal waves), and they conclude that the GM spectrum could be used as an input to acoustic fluctuation calculations. The measures of intensity fluctuations studied here, the SI and σ_ι, did not appear to be strongly influenced by the number of UTPs in the path—though a compensating effect due to differences in UTP depth cannot be ruled out. Some of the differences between the distributions of the simulated and measured intensities may be due to the shorter duration of the measured timeseries; an experiment with a longer duration would be required to resolve the ambiguity. Enhanced variability in the form of long-period deep fades is observed for paths turning in the extreme upper ocean; this enhanced variability is not predicted by the MCPE model employed here.

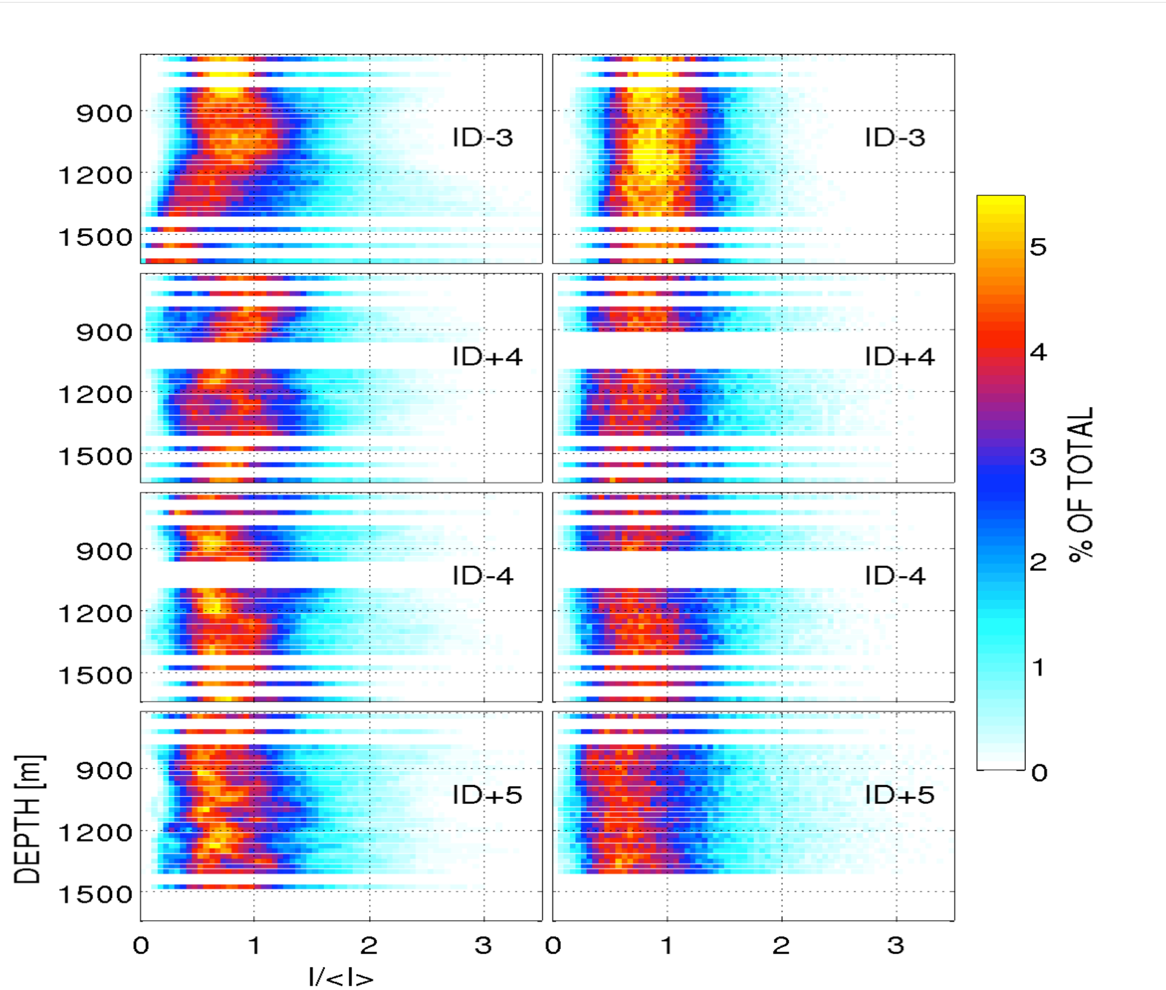

Figure 6. Shown in the left column are normalized histograms of I/⟨I ⟩ from the experiment. Shown in the right column are the same from the TD MCPE. Approximately 15 700 samples are included in the histograms at each depth for the measured data, while 4800 samples were included at each depth in the TD MCPE histograms.

Data from **PhilSea10** [1] and **LOAPEX** [5] were used to study the efficacy of using acoustic transmissions of m-sequence codes for underwater communication. Underwater communication has received intense activity for the past several years in the context of short-range high-frequency

applications. Many of the developments parallel the sophisticated progress in cell phone technology. When long-range communication, e.g. 50 km or more, is required data rates suffer.

The potential use of widely distributed platforms for various applications has highlighted the requirements for reliable long-range underwater communication of platform commands. In these applications, however, data rates may not be that important. For example when sending pre-arranged commands between widely distributed platforms a simple three-bit code can identify eight commands. If each of the bits is a maximal length sequence, or m-sequence, high signal to noise ratios and low bit error rates are possible. In addition, if the two m-sequences are nearly orthogonal to one another, decoding the command is relatively simple. If sufficient time is available for command recognition, relatively long and repeated sequences can be used to increase signal to noise ratios and lower bit error rates.

In our NPAL research maximal length sequences, a.k.a. m-sequences [6] have been used with great success. Typically a low-frequency carrier of 50 to 250 Hz is phase modulated between two states to form a sequence. The pattern of phase shifts is determined by a code generator based on an octal seed number. A commonly used sequence includes 1023 bits and the phase angle modulation is given by the arctangent of the square root of the number of bits. The period of the sequence is then determined by the bandwidth of the transmitter. The broader the bandwidth, the fewer the cycles of the carrier required to form a single bit. For example, a projector with a 50 Hz bandwidth at a carrier frequency of 100 Hz requires two cycles of the carrier to form a bit of the m-sequence.

When processed with a replica of the transmitted code the received signal is compressed to a time resolution of one bit length. In the example above, two cycles of the 100 Hz carrier would provide a resolution of 0.02 s. This resolution can often provide temporal separation of much of the multi-path arrival structure. The processing gain is 10logN, where N is the number of bits in the code. Further gains may be achieved by coherently averaging repetitions of the sequence.

Octal number code generators have been identified that produce nearly orthogonal codes, e.g. octal numbers 2033 and 3471. In other words, a received signal generated from 2033 and processed with a replica generated by 3471 produces no signal gain. Herein is the approach for a robust long-range, multi-path tolerant, simple three bit command code providing eight separate command codes. In this case the m-sequence, or repetitions of the same m-sequence, becomes the bit. For example, the command 101 might consist of 10 repetitions of code 2033 followed by 10 repetitions of code 3471, and finally 10 repetitions of code 2033.

Prior to examining real data we developed a methodology with simulated data. A m-sequence was generated in software having 1023 bits and a carrier frequency providing two cycles of the carrier for each bit. White noise was added to this signal to produce a signal to noise ratio of 4.89 dB. After low pass filtering the in-phase and quadrature components the phase of each bit is determined by an algorithm that examines the arctangent of the ratio of the in-phase component to the quadrature component. Results are shown in Figure 7 where the bit error rate was 1.86%.

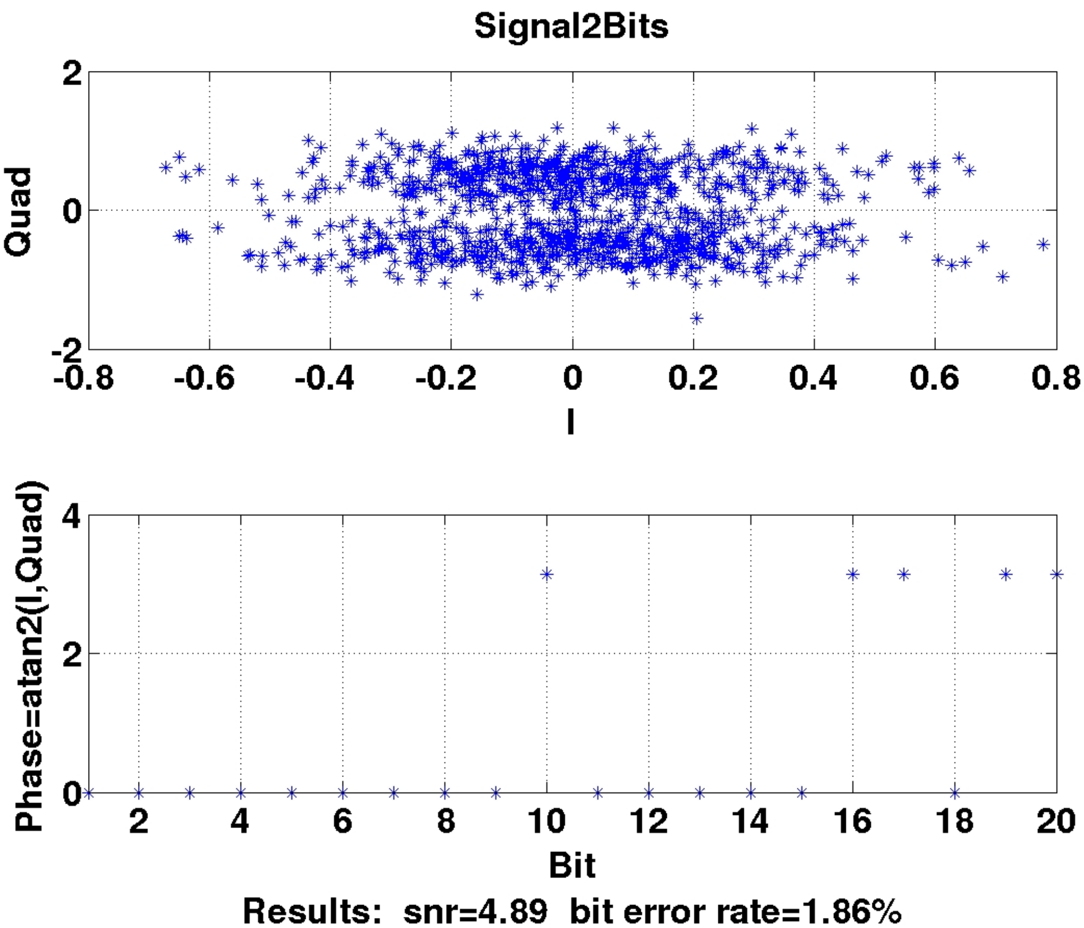

Figure 7. The upper panel shows the low-pass filtered quadrature components versus the in-phase (I) components. The lower panel indicates the phase separation (times 4) for a selected number of bits. The bit error rate (proper phase separation) was 1.86% for all 1023 bits.

In the case of real world data ambient noise is not the only problem. The transmitted signal is not ideal due to transducer limitations and the received signal will also be distorted due to ocean sound speed variability. Figure 8 shows the reception of a portion of the 8th m-sequence in a series of repeated sequences on hydrophone #7 of the upper array during **LOAPEX**. Figure 9 presents the results for the entire 1023 bit sequence after applying the methodology described above. The bit error rate for all 1023 bits in this case was 0.78%.

As mentioned above, it is typically possible to achieve additional gain by coherently averaging several m-sequences. Figure 10 presents results for **LOAPEX** transmissions from 50, 250, and 500 km to the 7th hydrophone of the upper array. The figure shows the improvement in average bit error rate by coherently summing 10 m-sequences (red stars) compared to using only one m-sequence (blue stars).

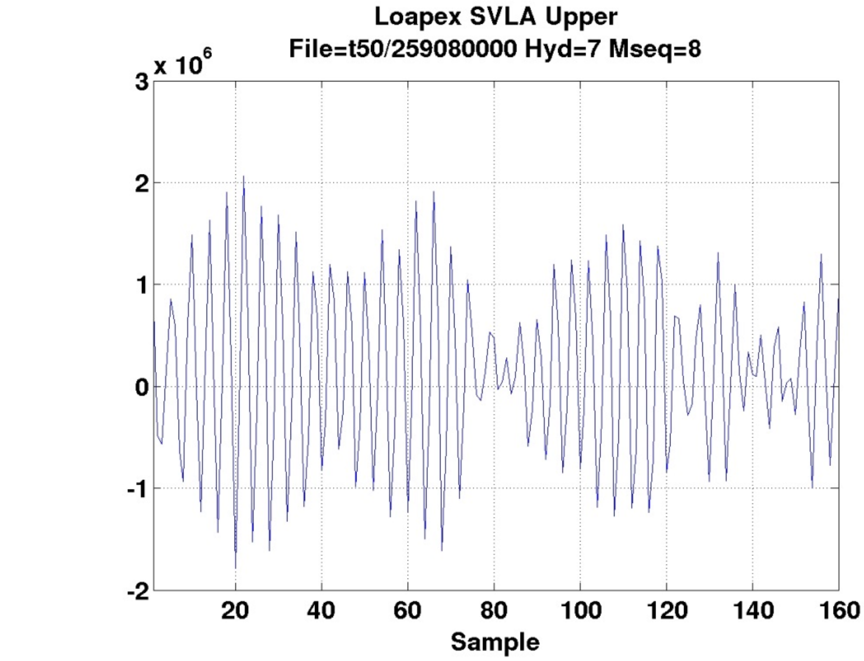

Figure 8. A portion of the 8th m-sequence as received on hydrophone #7on the upper array from a range of 50km during LOAPEX.

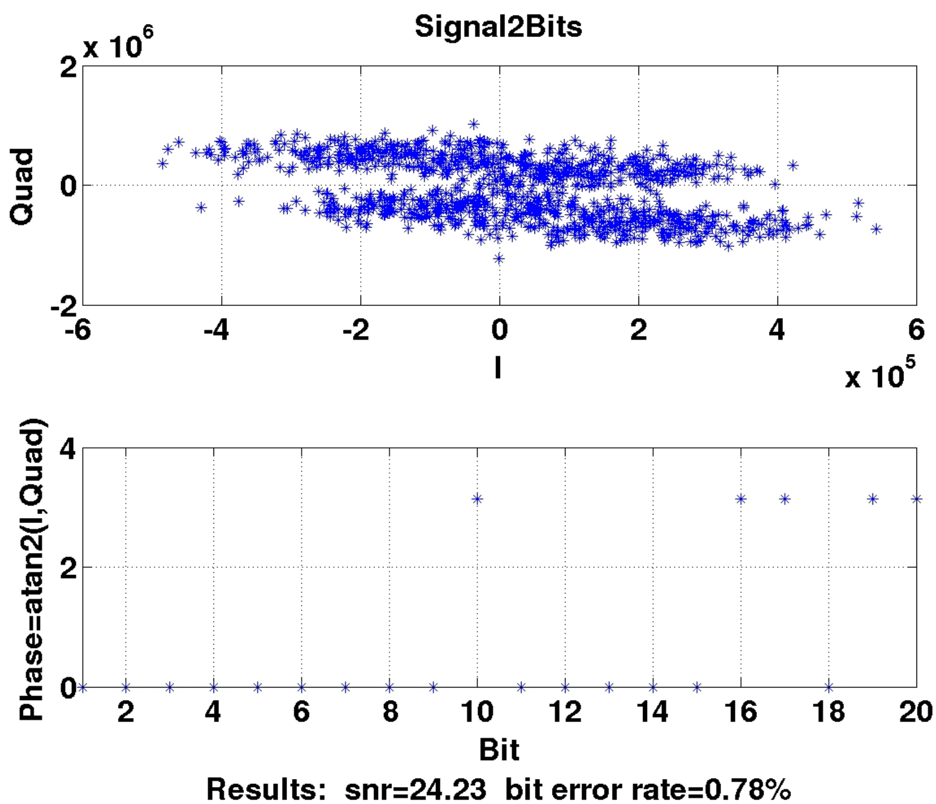

Figure 9. Similar to Figure 7 but with real data.

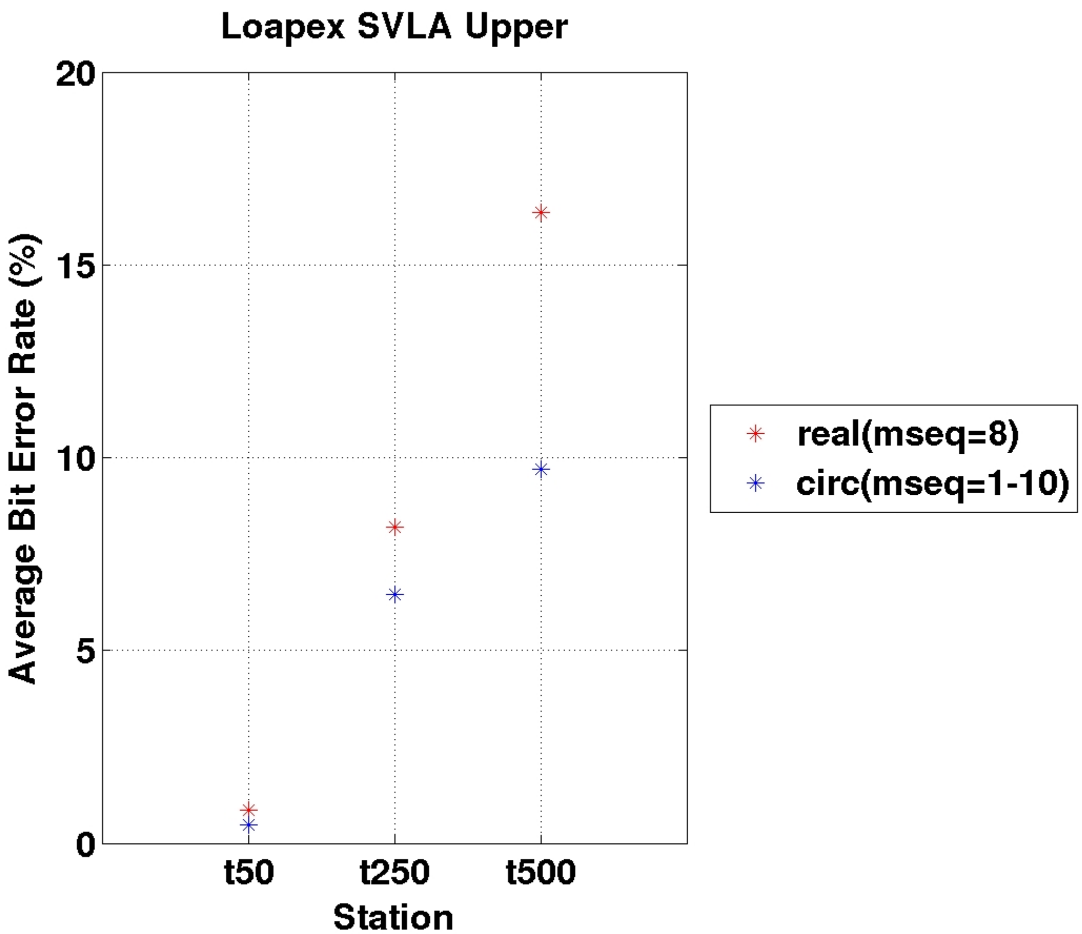

Figure 10. A comparison of average bit error rates at ranges of 50, 250, and 500 km, using a single m-sequence (red stars) and 10 coherently summed m-sequences (blue stars).

We examined the received signals in detail to determine when the bit errors occurred and found that the errors occurred most frequently when a bit containing only two cycles of the carrier was followed by another bit containing only two bits of the carrier. Fewer errors occurred when the transition involved at least one bit with more than two cycles of the carrier. The problem is related to the finite bandwidth of the transducer and the rise time of the signal following a phase transition.

Even with bit error rates of 10-20% it is relatively easy to identify the m-sequence when processed with the correct replica of the m-sequence. The scheme proposed to create an eight-bit code using nearly orthogonal m-sequences only requires the identification of the proper m-sequence. During the **PhilSea10** experiment two orthogonal m-sequences were simultaneously transmitted over a range of 500 km. When processed with the correct law, signal to noise ratios over 20 dB were observed. When processed with the incorrect law, the signals could not be detected. The two significant processing issues for this scheme are identifying the starting bit of each m-sequence, and if Doppler is present, a search in Doppler space must be conducted to maximize signal to noise ratio. Nevertheless, it is practical to use nearly orthogonal m-sequences to send simple codes over very long distances.

COLLABORATIONS

A large number of additional investigators have been involved in ONR-supported research related to the NPAL project and participate in the NPAL Workshops, including Art Baggeroer (MIT), J. Beron-Vera (UMiami), M. Brown (UMiami), T. Chandrayadula (NPS), J. Colosi (NPS), N. Grigorieva (St. Petersburg State Marine Technical University), F. Henyey (APL-UW), V. Ostashev (NOAA/ETL), R. Stephen (WHOI), I. Udovydchenkow (WHOI), A. Voronovich (NOAA/ETL), K. Wage (George Mason Univ.), Peter Worcester (Scripps), and others. In addition, we have begun close collaboration with Gerald D'Spain (MPL).

IMPACT/APPLICATIONS

This research has the potential to affect the design of long-range acoustic systems, whether for acoustic surveillance, communication, or remote sensing of the ocean interior. The data from the NPAL network, and the special NPAL experiments, indicate that existing systems do not exploit the limits of acoustic coherence at long ranges in the ocean. Estimates of basin-wide sound speed (temperature) fields obtained by the combination of acoustic, altimetry, and other data types with ocean general circulation models have the potential to improve our ability to make the acoustic predictions needed for matched field and other sophisticated signal processing techniques and to improve our understanding of ocean variability.

PUBLICATIONS (Refereed)

Chandrayadula, Tarun K., Kathleen E. Wage, Peter F. Worcester, Matthew A. Dzieciuch, James A. Mercer, Rex K. Andrew, and Bruce M. Howe, "Reduced rank models for travel time estimation of low mode signals," *J. Acoust. Soc. Am.,* in press.

Udovydchenkov, Ilya A., Michael G. Brown, Timothy F. Duda, Peter Worcester, Matthew A. Dzieciuch, James A. Mercer, Rex K. Andrew, Bruce M. Howe, and John A. Colosi, "Weekly dispersive modal pulse propagation in the North Pacific Ocean," *J. Acoust. Soc. Am.,* NPAL special issue.

Chandrayadula, Tarun K., Peter F. Worcester, Matthew A. Dzieciuch, James A. Mercer, Rex K. Andrew, and Bruce M. Howe, "Observations and transport theory analysis of low frequency, long range acoustic mode propagation in the Eastern North Pacific Ocean," *J. Acoust. Soc. Am.,* in press.

Freeman, S. E., D'Spain, G. L., Lynch, S. D., Stephen, R. A., Heaney, K. D., Murray, J. J., Baggeroer, A. B., Worcester, P. F., Dzieciurch, M. A., and Mercer, J. A., "Estimating the horizontal and vertical direction-of-arrival of water-borne seismic signals in the northern Philippine Sea," *J. Acoust. Soc. Am.,* in press.

Heaney, K. D., Campbell, R. L., Murray, J. J., Baggeroer, A. B., Scheer, E. K., Stephen, R. A., D'Spain, G. L., and Mercer, J. A., "Deep water towed array measurements at close range," *J. Acoust. Soc. Am.,* in press.

Stephen, R. A., Bolmer, S. T., Udovydchenkov, I. A., Worcester, P. F., Dzieciuch, M. A., Andrew, R. K., Mercer, J. A., Colosi, J. A., and Howe, B. M., "Deep seafloor arrivals in long range ocean acoustic propagation," *J. Acoust. Soc. Am.,* in press.

White, A. W., Andrew, R. K., Mercer, J. A., Worcester, P. F., Dzieciuch, M. A., and Colosi, J. A., "Wavefront intensity statistics for 284-Hz broadband transmissions to 107-km range in the Philippine Sea: observations and modeling," *J. Acoust. Soc., Am.,* in press.

Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., Dushaw, B. D., Baggeroer, A. B., Heaney, K. D., D'Spain, G. L., Colosi, J. A., Stephen, R. A., Kemp, J. N., Howe, B. M., Van Uffelen, L. J., and Wage, K. E., "The North Pacific Laboratory (NPAL) deep-water acoustic propagation experiments in the Philippine Sea," *J. Acoust. Soc. Am.,* in press.

Lynch, Stephen D., Gerald L. D'Spain, Kevin D. Heaney, Richard Campbell, Arthur B. Baggeroer, James Mercer, and Peter Worcester, "Dependence of the structure of the shallow first convergence zone in the deep ocean on bathymetry and sound speed variability," *J. Acoust. Soc. Am.*, in preparation.

(Note: Papers listed last year as submitted by Andy Ganse, Rex Andrew, and Frank Henyey were either rejected or are still in revision.)

REFERENCES

[1] Worcester, P. F., Dzieciuch, M. A., Mercer, J. A., Andrew, R. K., Dushaw, B. D., Baggeroer, A. B., Heaney, K. D., D'Spain, G. L., Colosi, J. A., Stephen, R. A., Kemp, J. N., Howe, B. M., Van Uffelen, L. J., and Wage, K. E., The North Pacific Acoustic Laboratory (NPAL) deep-water acoustic propagation experiments in the Philippine Sea, *J. Acoust. Soc. Am.,* in press.

[2] RK Andrew, "APL/UW Removable Hard Drives", 20 February 2012.

[3] W. H. Munk. Internal waves and small-scale processes. In C. Wunsch and B. Warren, editors, The Evolution of Physical Oceanography, pages 264–291. MIT Press, Cambridge MA, 1981

[4] J. A. Colosi, L. J. Van Uffelen, B. D. Cornuelle, M. A. Dzieciuch, P. F. Worcester, B. D. Dushaw, and S. R. Ramp. Observations of sound-speed fluctuations in the western Philippine Sea in the spring of 2009. J. Acoust. Soc. Am., In press

[5] Mercer, J. A., Colosi, J. A., Howe, B. M., Dzieuciuch, M. A., Stephen, R., and Worcester, P. F., LOAPEX: The Long-Range Ocean Acoustic Propagation EXperiment, *IEEE J. of Ocean. Eng.,* **34**, (1), 2009.

[6] Metzger, K., *Signal Processing Equipment and Techniques for Use in Measuring Acoustic Multipath Structures* (Ph.D. Dissertation, University of Michigan Dissertation Services, 1983) 305 pp. 305.